Advanced FIB preparation of semiconductor specimens for examination by off-axis electron holography.

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Off-axis electron holography is a TEM based technique that can be used to reconstruct phase and amplitude images of a specimen from an interference pattern that is formed by using an electron biprism. As the phase of an electron is very sensitive to changes in potential in a specimen, such as from the presence of dopants, electron holography can be used to fulfil the requirements of the semiconductor industry for a technique that can quantitatively map dopants with nm-scale resolution [1].

Focused ion beam (FIB) milling is a promising technique that can be used to prepare state of the art semiconductor devices for examination by electron holography due to its ease of use and excellent site specificity. However, the FIB introduces many artefacts into the specimens in the form of Ga implantation and damage of the specimen surfaces that are observed in the form of an amorphous layer and electrically 'inactive' layer [2]. The presence of the electrically 'inactive' thickness results in experimental phase measurements across the *p-n* junctions that are much smaller than are predicted by theory.

Focused ion beam milling is known to generate defects deep into the specimen, and it is proposed that these defects lie in mid-band gap energy states in GaAs and Si, giving rise to the thick electrically 'inactive' layers that are observed experimentally. We will show that by annealing the specimens *in situ* in the transmission electron microscope, the concentration of these defects in the specimens is reduced, and the dopants are re-activated thereby increasing the experimental phase change measured across the junction. The electrically inactive thickness is reduced and an improvement in the signal-to-noise ratio is observed in the phase images.

Figure 1. shows phase images of a 240-nm-thick GaAs specimen containing a symmetrical 1×10^{18} cm^{-3} doped *p-n* junction (a) before and (b) after a 500 °C *in situ* anneal. The improvement in the signal-to-noise ratio is clear. Figure 2.(a) shows the phase measured across a 300-nm-thick GaAs specimen before and after annealing showing the increase in the phase measured across the junctions. Figure 2.(b) shows the

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step in phase measured across a series of junctions as a function of the crystalline specimen thickness measured using convergent beam electron diffraction (CBED) both before and after a 500 °C anneal. By extrapolating the gradients to the *x*-axis the electrically 'inactive' thickness of the specimen is shown to have been reduced from 80 to 17 nm on each surface after annealing. We will also show that by annealing Si *p-n* junctions *in situ* at a temperature of only 300 °C, the electrically inactive layer is reduced from 25 to 5 nm [3]. New results from using a LASER to anneal the specimens will also be presented.

We will show that by reducing the operating voltage of the FIB we can reduce the electrical damage to both Si and GaAs specimens. Finally, we will discuss the effects of using ions other than Ga, such as Si, Ar and O to prepare semiconductor specimens for examination using off-axis electron holography.

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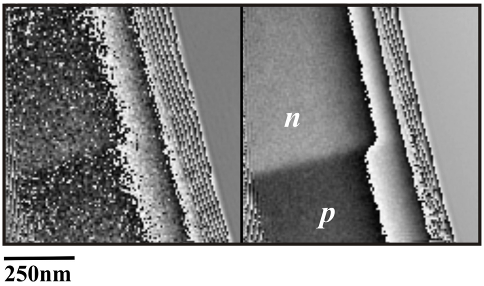

Figure 1. Shows phase image of a 240-nm-thick GaAs specimen containing a *p-n* junction recorded (a) immediately after ion milling and (b) after a 500 °C *in situ* anneal.

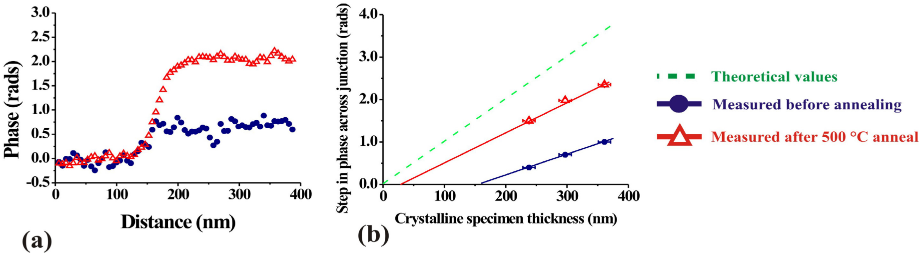

Figure 2. (a) Shows phase profiles acquired across a GaAs specimen containing a *p-n* junction before and after an in situ anneal at 500 °C. (b) Shows the step in phase measured across a series of *p-n* junctions as a function of the specimen thickness measured by CBED.